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The adaptability of shortseason soybean genotypes to varying longitudinal regions

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Abstract

In the present paper, we wanted to determine the soybean genotypes' adaptability to conditions different from those they are usually grown in—different in terms of climate, soil and agronomic practices. We therefore studied the adaptability of northern soybean genotypes (maturity groups 00–II) to two very distant locations with similar latitudes. One is Novi Sad, Serbia, where the varieties have been developed, while the other is Memuro on the island of Hokkaido in Japan. The results of the study showed there were differences among environments for all traits except plant height and seed weight. Although there was an overall positive correlation between the growth period and yield, we also found a difference in yield due to an interaction between environment and variety. The varieties with a longer growing season had higher average yields in favorable years. Plant height and seed weight were generally greater in Japan than in their country of origin due to higher rainfall in Japan. The coefficients of correlation among the traits varied depending on the environment.

Keywords: Soybean; Adaptability; Environment

1. Introduction

Soybean (*Glycine max* (L.) Merr.) is grown in Serbia as a full-season crop in conventional systems and as a second crop in double-cropping systems, where it is planted following the harvest of small grains. Full season usually means planting in April and harvesting in September, but this period may be almost a month longer or shorter depending on environmental conditions.

The possibility of precisely predicting plant developmental stages is of great practical importance in the sense that it makes it easier to make decisions on when to apply a certain cultural practice, which should be paired with a specific stage of plant development for maximum efficacy (Bauer et al., 1984). The assessment of phenological development as a function of specific environmental variables is a basic piece of information necessary for any attempt at modelling plant growth, adaptation and productivity as a dynamic process (Jones and Laing, 1978; Davidson and Campbell, 1983; Hodges and French, 1985; Wang et al., 1987; Colson et al., 1995). Soybean phenology, however, is hard to predict, because it depends on the photoperiod (Borthwick and Parker, 1939; Garner and Allard, 1930; Seddigh et al., 1989) and temperature (Board and Hall, 1984; Egli and Wardlaw, 1980) as well as the amount of water available to the plant (Blanchet et al., 1989; Meckel et al., 1984). However, other factors, like soil fertility, resistance to specific diseases or insects, or resistance to lodging under rainy conditions, are also important (Haile et al., 1998; Tanner and Hume, 1978).

The longer growing seasons result in higher potential crop production, defined by the insolation available when temperatures are suitable for plant growth (de Wit, 1967). Assuming there is no water limitation, biomass production is the product of the solar radiation over the duration of the crop period (Richards, 2000). So, a longer crop period means greater biomass, and according to Rao et al. (2002), biomass is an important determinant of seed yield. Egli and Bruening (1992) provided evidence that, in the absence of water stress, lower levels of insolation during reproductive growth were a major contributor to the yield

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loss, with temperature only becoming important for very late maturing varieties. However, investigations in dry conditions showed that in droughty years early varieties may have yields that are the same as or even higher than those of the late ones (May et al., 1989; Kane and Grabau, 1992; Savoy et al., 1992; Mayhew and Caviness, 1994). Because of their longer growing season, late varieties go through the critical stages of grain formation and grain fill during the most unfavorable part of the season (second half of July and first half of August) when the air temperature is at its highest and the possibility of drought is the greatest, which negatively affects the yield. Varieties with a shorter growing season go through this critical phase earlier and faster, so their yields are less reduced in dry conditions than those of the late varieties.

Soybean development can be divided into two stages—vegetative and reproductive (Fehr and Caviness, 1977). Soybean plants are photoperiodically sensitive, meaning that the transition from the vegetative stage to the reproductive stage depends directly on daylength. The critical photoperiod (length of the vegetative period) of soybean varieties increases progressively with higher latitude. Flowering and maturity occurs later, and plants may even fail to reach full maturity before the onset of first frosts. When grown at lower latitudes, the same varieties will flower earlier, have a smaller vegetative mass, and mature earlier, resulting in lower yield (Lima et al., 2000). Photoperiod requirements, therefore, limit the geographic distribution of a variety to a narrow belt of latitude (around 200 km, Scott and Aldrich, 1983) to which a variety has been adapted. For every soybean-growing are a, therefore, there is an optimum maturity group. Varieties that are one maturity group earlier than the optimum are too early for the area concerned, and vice versa, those that are one group later are too late.

No such limitations exist with longitude, so a variety can, presumably, be grown throughout the latitude it is adapted to regardless of longitude. However, few attempts have been made to study this. According to Lin and Binns (1991, 1994), genotype response to differences among locations can be defined as adaptability, and response to differences among years as stability. Thus, a variety's success in spreading across an area depends on its adaptability.

A multilocation trial is usually a reliable indicator of a variety's adaptability. This kind of trial is usually carried out in locations representative of the area the variety is grown in and usually does not stray far to the north or south of the optimum latitude, so as to fully exploit the genotype's genetic potential for yield. Although there are no limitations regarding photoperiodic response, the distance along the east-west axis reaches only as far as the climatic and/or soil conditions will allow. The combination of distances along the two axes defines the geographic distribution of a variety or the area suitable for its production. The results of multilocation trials therefore usually provide a picture of a variety's adaptedness to particular areas within a larger area for which the variety was developed and in which it is being produced.

In the present paper, we studied the adaptability of northern soybean varieties (maturity groups 00–II) to two very distant locations with similar latitudes in order to determine if the variety can be grown productively at very different longitudes. One is Novi Sad, Serbia, where the varieties have been developed, while the other is Memuro on the island of Hokkaido in Japan. The varieties in question are successfully grown in Serbia as well as in the neighbouring countries of Italy, Hungary and Romania. We therefore wanted to determine the soybeans varieties' adaptability to conditions different from those they are usually grown in—different in terms of climate, soil and agronomic practices.

2. Materials and methods

Four soybean varieties developed at the Institute of Field and Vegetable Crops in Novi Sad—Danica, a very early variety from maturity group 00; Afrodita, an early variety from maturity group 0; Ravnica, a medium early variety from maturity group I, and Vojvodjanka, a late variety from maturity group II were used in the study. These varieties are leading ones currently being produced in Serbia and surrounding countries.

The trials were carried out at two locations over a period of 3 years. Two locations with similar temperature during the growth period were chosen. One site was the Institute of Field and Vegetable Crops in Novi Sad, where the varieties were developed. Novi Sad is situated at 45°16′N and 19°51′E at an altitude of about 80 m. The dominant soil type at the field where the tests were grown is calcareous chernozem with a pH of 7.65 and organic matter content of 3.3%. The trials were conducted during the 1997 and 1998 growing seasons. Meteorological data for the 2 years are shown in Fig. 1. In both years planting was done in April, which is considered to be the optimum time for planting in Serbia. Planting was done in the traditional Serbian way, which was plant-to-plant spacing of 3–4 cm within a row. Plots were four rows wide and 5 m long with a 0.5 m row-to-row spacing.

The other site was the Hokkaido Prefectural Tokachi Agricultural Experiment Station in Memuro, Japan. Memuro is located at 42°55′N and 143°03′E at 98 m altitude. The dominant type of soil at the location is volcanic ash soil (andisol). This part of the

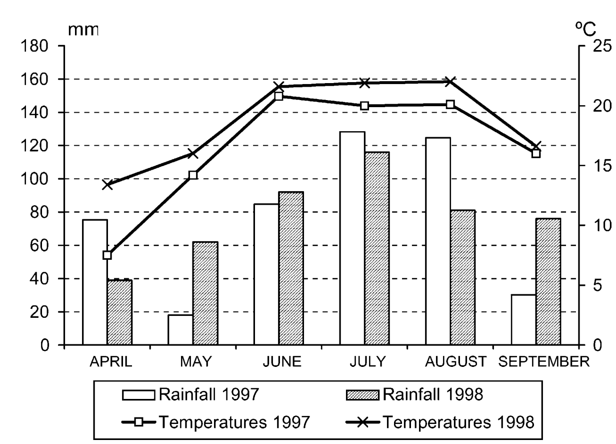

Fig. 1. Rainfall and temperatures for the growth periods 1997 and 1998 in Novi Sad.

study was conducted during the growing seasons of 1998 and 1999. Fig. 2 shows meteorological data for both years. Planting was done in two ways: the traditional Serbian way mentioned above and the traditional Japanese way. In Japan two plants were planted together in a hill, with 20 cm between hills. A plot was four rows wide and three meters long with a 0.6 m row-to-row spacing.

A completely randomized block design with three replicates was used.

The following traits were investigated:

- grain yield, adjusted to 14% moisture and expressed as $Mg\,ha^{-1}$;
- plant height (cm);
- 1000-seed weight (g);
- harvest index (seed weight/total biomass ratio);
- vegetative period duration (days);
- reproductive period duration (days);
- daylength during vegetative period (h);
- daylength during reproductive period (h);
- oil content (%);
- protein content (%).

Data were processed by analysis of variance to determine possible differences among the varieties and the various levels of interaction. For easier calculation, the two-factorial ANOVA model was used. Variety was the first factor and environment the second, where E1: 1997 in Serbia, E2: 1998 in Serbia, E3: 1998 in Japan with the Serbian planting, E4: 1998 in Japan with the Japanese planting, E5: 1999 in Japan with the Serbian planting, and E6: 1999 in Japan with the Japanese planting. Although some of the research at one location was conducted in a year when there was no research at the other location, the sites are far enough apart that climatic events at one location would not affect those at another. Therefore, conducting the experiment in the same or different years at the two locations should not be an issue.

Testing of differences between the traits means was done using the *t*-test by calculating the least significant difference according to Steel and Torrie (1980).

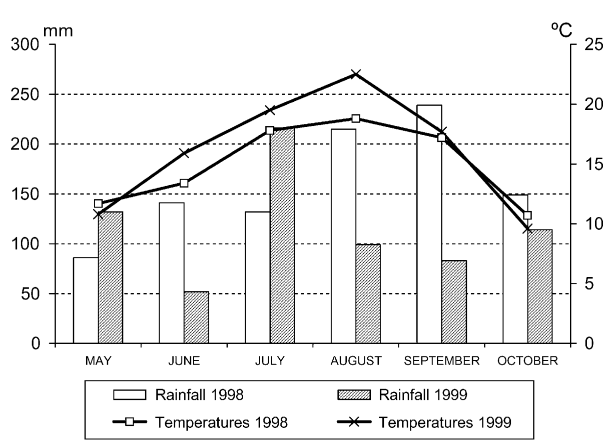

Fig. 2. Rainfall and temperatures for the growth periods 1998 and 1999 in Memuro.

Table 1
Two-way ANOVA for investigated traits

Source	d.f.	Yield ($Mg\,ha^{-1}$)	Plant height (cm)	Seed weight (g)	Harvest index	Vegetative period, *V* (days)	Reproductive period, *R* (days)	Daylength during vegetative period (h)	Daylength during reproductive period (h)	Protein (%)	Oil (%)
Mean squares											
Environment (E)	5	13.033**	457.647 ns	2332.956 ns	0.056**	1642.922**	1155.447**	426930.277**	427700.859**	27.521**	5.928**
Variety (V)	3	5.162*	861.025*	12873.447**	0.002 ns	253.685**	923.051**	22190.632**	115180.075**	26.360**	16.003**
E × V	15	0.991**	178.191**	1031.742*	0.004**	43.930**	36.551**	1525.866**	6493.755**	2.539**	0.690**
Error	46	0.091	22.634	232.298	0.0002	0.461	0.635	100.607	106.801	0.412	0.116
CV, %		7.83	4.54	7.65	3.24	1.73	0.92	1.64	0.87	1.64	1.60

*,**Significant at the 0.05, and 0.01 probability levels, respectively; ns, non-significant.

Table 2
Investigated traits over varieties

Variety	Yield (Mg ha$^{-1)}$	Plant height (cm)	Seed weight (g)	Harvest index	Vegetative period (days)	Reproductive period (days)	Daylength during *V* period (h)	Daylength during *R* period (h)	Protein (%)	Oil (%)
Danica	3.10 c	97.35 b	172.64 c	0.500 c	34.22 d	76.00 d	570.97 d	1070.19 c	37.76 c	22.63 a
Afrodita	3.87 b	100.53 b	236.33 a	0.510b c	39.00 c	88.39 c	592.78 c	1215.64 b	40.68 a	20.47 c
Ravnica	4.16 a	109.70 a	196.50 b	0.515 ab	42.67 a	89.72 b	647.75 a	1220.02 b	38.79 b	21.10 b
Vojvodjanka	4.30 a	111.57 a	191.83 b	0.524 a	41.56 b	91.94 a	631.34 b	1247.40 a	38.92 b	20.87 b
LSD (0.05)	0.20	3.19	10.23	0.011	0.46	0.53	6.73	6.93	0.43	0.23

Values marked with different letters (a–d) within the same column differ significantly at the 0.05 probability level.

To reduce the dimensionality of a data set comprised of a large number of mutually correlated variables while retaining the maximum possible amount of variability that is present in the data, a multivariate analysis method called principal components analysis (PCA) is used. Essentially, a set of correlated variables is transformed into a set of uncorrelated variables which is ordered by reducing variability. The uncorrelated variables are linear combinations of the original variables, and the last of these variables can be removed with minimum loss of real data (Jolliffe, 1986; Causton, 1987).

Correlations among the traits were calculated using the general correlation formula (Singh and Chaudhary, 1979):

$$r_{xy} = \frac{\mathrm{Cov}_{xy}}{\sqrt{\sigma_x^2\sigma_y^2}}$$

r is correlation between x and y, Cov_{xy} covariance between x and y, σ_x^2 variance of x, σ_y^2 is variance of y.

Only differences between means or correlations significant at $P < 0.05$ are considered in the text.

3. Results

The results of the study showed there were differences among the environments for all the traits except plant height and seed weight (Table 1). There were differences among the varieties for all the traits measured, except for the harvest index. The variety with the highest average yield was Vojvodjanka, believed to have the highest genetic potential for yield (Table 2). Still, the yield produced by Vojvodjanka was not higher than that of Ravnica. No differences were found between these two varieties for any of the traits except growing season length (which is to be expected as they belong to different maturity groups). Afrodita had a lower yield than the above two varieties, but it outyielded Danica. The highest and lowest yields were observed for Novi Sad (E1 and E2, Table 3). Thus, the yields of Memuro (E3–E6) were between the yields of Novi Sad. The varieties with a longer growing season (Vojvodjanka and Ravnica, Table 4) had higher average yields in favorable years (E1, E5 and E6).

Using PC analysis, three main components were identified (Fig. 3). The first one, which explained 58.92% of the total

Table 3
Investigated traits over environments

Environment	Yield (Mg ha^{-1})	Plant height (cm)	Seed weight (g)	Harvest index	Vegetative period (days)	Reproductive period (days)	Daylength during *V* period (h)	Daylength during *R* period (h)	Protein (%)	Oil (%)
E1	5.44 a	93.07 c	182.83 b	0.477 c	36.25 d	94.75 b	549.01 d	1378.69 b	38.48 c	21.10 c
E2	2.57 e	104.32 b	181.05 b	0.390 d	17.25 e	102.00 a	265.07 e	1476.13 a	39.42 b	21.58 b
E3	2.87 d	104.93 b	206.50 a	0.542 b	48.17 a	83.58 c	768.49 a	1090.63 c	40.48 a	20.57 d
E4	3.76 c	107.03 ab	214.58 a	0.537 b	48.33 a	83.17 c	770.95 a	1091.13 c	40.93 a	20.41 d
E5	4.18 b	109.66 a	203.83 a	0.567 a	42.75 c	77.66 d	650.33 c	1046.18 d	37.03 e	22.21 a
E6	4.31 b	109.72 a	207.17 a	0.563 a	43.42 b	77.75 d	660.42 b	1047.12 d	37.89 d	21.75 b
LSD (0.05)	0.25	3.91	12.52	0.01	0.56	0.65	8.24	8.49	0.53	0.28

Values marked with different letters (a–e) within the same column differ significantly at the 0.05 probability level.

Table 4
Yields of the varieties over environments (Mg ha^{-1})

Variety	E1	E2	E3	E4	E5	E6
Danica	3.37 hij	2.44 mn	2.59 lmn	3.17 ijk	3.48 ghij	3.53 ghi
Afrodita	4.99 b	2.30 n	3.09 ijkl	4.19 def	4.26 cdef	4.37 cde
Ravnica	6.49 a	2.82 klm	2.77 klmn	3.77 fgh	4.48 cd	4.61 bcd
Vojvodjanka	6.88 a	2.73 klmn	3.03 jkl	3.93 efg	4.50 bcd	4.72 bc

LSD 0.50. Values marked with different letters (a–n) differ significantly at the 0.05 probability level.

Table 5
Principal component analysis results

	Component loadings		
	Component 1	Component 2	Component 3
Variance explained by traits			
Daylength during reproductive period (DR)	−0.988	0.096	0.114
Harvest index (HI)	0.971	−0.186	0.129
Reproductive period (RP)	−0.965	0.255	0.048
Seed weight (SW)	0.951	0.193	−0.186
Vegetative period (VP)	0.940	0.167	0.288
Daylength during vegetative period (DV)	0.930	0.242	0.259
Plant height (PH)	0.590	−0.188	−0.770
Protein (PR)	−0.01	0.992	−0.098
Oil (OL)	−0.138	−0.947	−0.286
Yield (YI)	0.135	−0.464	0.846
Variance explained by components	5.892	2.364	1.616
Percent of total variance explained	58.921	23.639	16.165

Table 6
Simple correlations (r) between investigated traits over environments

Correlation pair	E1	E2	E3	E4	E5	E6
Plant height, yield	0.90**	0.26 ns	−0.61*	0.19 ns	0.02 ns	0.56*
Seed weight, yield	−0.60*	0.10 ns	0.59*	0.84**	0.12 ns	0.06 ns
Vegetative period, yield	0.94**	0.52 ns	0.44 ns	0.67*	0.68*	0.50 ns
Reproductive period, yield	0.95**	0.32 ns	0.61*	0.86**	0.87**	0.84**
Daylength during V, yield	0.94**	0.52 ns	0.24 ns	0.40 ns	0.68*	0.49 ns
Daylength during R, yield	0.95**	0.29 ns	0.61*	0.86**	0.85**	0.84**
Protein, yield	−0.32 ns	−0.51 ns	0.43 ns	0.90**	0.39 ns	0.66*
Oil, yield	0.12 ns	0.06 ns	0.49 ns	−0.86**	−0.66*	−0.87**
Seed weight, protein	0.69**	−0.14 ns	0.85**	0.90**	0.84**	0.73**
Seed weight, oil	−0.74**	−0.69**	−0.74**	−0.75**	−0.63*	−0.44 ns
Oil, protein	−0.52 ns	−0.04 ns	−0.86**	−0.91**	−0.91**	−0.85**

*,** Significant at the 0.05, and 0.01 probability levels, respectively; ns, non-significant.

variance, included daylength during the reproductive period, harvest index, reproductive period duration, seed weight, vegetative period duration and daylength during vegetative period, respectively. The second component, which explained 23.63% of the total variance, included protein and oil content. The third component, explaining 16.16% of the total variance, included yield and plant height (Table 5).

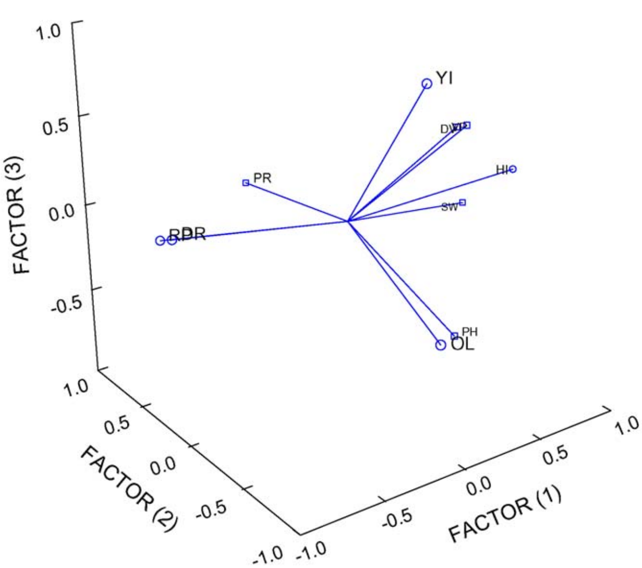

Fig. 3. Factor loadings plot.

The coefficients of correlation between the investigated traits varied depending on the environment (Table 6). Generally, there were positive correlations between yield and both growth periods as well as between yield and daylength during both periods. Though expected, there were no clear negative correlations between yield and protein content and no clear positive correlations between yield and oil content. However, there were clear negative correlations between oil and protein content.

4. Discussion

On average, the varieties were ranked in the order of their growing season length, as those with a longer season had higher yields. Over environments, however, this regularity could be observed in favorable years in both locations (E1, E5 and E6). In Memuro, in the year with the lower yield, the early variety Afrodita had a higher yield than the later-maturing varieties in both planting treatments (E3, E4), whereas in 1998 in Novi Sad, where the lowest average yield was obtained (E2), the very early variety Danica had a yield that was higher than that of Afrodita and on par with those of the late varieties. Therefore, it could be said that later-maturing varieties with higher genetic potentials for yield need favorable growing conditions as well in order for that potential to be realized. In years with unfavorable growing conditions, the yields of these varieties (Ravnica and Vojvodjanka) were much more affected by environmental factors than the yields of varieties with a shorter growing season (Danica and Afrodita). Therefore, tested varieties with a shorter growing season may be said to have higher yield stability.

The yield components, plant height and seed weight, were greater in Japan than in their country of origin. The values were distributed very evenly, so there was no variation in seed weight in the same location in different years. The larger grain size resulted in a larger harvest index in Japan than in Novi Sad, regardless of the total biomass production. These differences were a result of the higher amount of precipitation in Japan than in Novi Sad. The formation of final yield, however, was much more affected by the distribution of precipitation during the growth period and, especially, the reproductive period. In Novi Sad, there was a highly favorable distribution of precipitation with abundant rainfall in the second half of July and first half of August in 1997 (Fig. 1), the time that coincided with the period of grain formation and grain filling, critical for yield (Miladinovic, 1997; Board, 2002). This was the most important factor for the obtainment of the highest yield in E1.

In 1998, in addition to less mid-season precipitation and somewhat higher temperatures, there was abundant precipitation in September, which slowed maturation, delayed harvesting and caused seed losses due to pod dehiscence. This generally had a negative effect on the yields of all the varieties, especially those with a longer growing season. Such an unfavorable distribution of precipitation also gave rise to a non-effective prolongation of the reproductive period, resulting in higher daylength values. As a result, there was not a clear relation between the reproductive period duration and yield and daylength during reproductive period and yield for E2. In Memuro, there was too much rainfall in August and September of 1998 (twice as much as in 1999, Fig. 2). This period, also important for grain formation and grain filling, saw excessive rainfall, too great for normal grain formation and filling, causing severe lodging and delayed maturation. This resulted in lower yields in E3 and E4 compared to E5 and E6.

In favorable growing conditions, the varieties produced the highest grain yields at Novi Sad (E1), the location where they were developed. However, high yields were obtained in Memuro as well (E5 and E6 in 1999), showing that a variety can be grown productively at very different longitudes as long as the latitude is similar. Because bigger differences among the varieties were observed between years within the same location than between the locations themselves, the varieties appeared to have excellent adaptability. As regards the different planting methods at Memuro, the Japanese method produced higher yields than the Serbian method in both years. This indicates that the Japanese method is more suited to the Japanese climate and condition.

PCA reduced the original data set to three sets of uncorrelated variables, ordered by reducing variability (Table 5). The variable containing the maximum amount of variation for the first set was daylength during reproductive period, whereas the variation of duration of vegetative period and daylength during vegetative period was not significant. The second variable containing the maximum amount of variation unexplained by the first and orthogonal to the first was protein content, while the third, containing the maximum amount of variation unexplained by the first and second and orthogonal to the first and second, was yield.

The coefficients of correlation among the traits varied depending on the environment (Table 6). In 1997 at Novi Sad (E1), they were the closest to our expectations—a strong positive correlation between yield and duration of both growing periods and a strong negative correlation between yield and seed weight. Studies by other authors (Rao et al., 2002) report a variable relationship between yield and seed weight in different locations. The relation between yield and protein content was negative, which is in agreement with other studies (Thorne and Fehr, 1970; Simpson and Wilcox, 1983; Leffel and Rhodes, 1993; Miladinovic et al., 1997; Cober and Voldeng, 2000). While the physiological reasons for this are not known, it is often attributed to competition for photosynthate between the N fixing root nodules and developing seeds in the pods (Burton, 1987). The relationship between oil and protein was negative and in agreement with Hymowitz et al. (1972), Leffel (1988), Miladinovic et al. (1996) and Yaklich et al. (2002), hence, the relation between yield and oil content was positive.

In 1998 at Novi Sad (E2), only one correlation occurred, namely a negative one between seed weight and oil content. At Memuro, however, positive correlations with the Japanese way of planting were found between yield and protein content. Thus, negative correlations were found between yield and oil content, except in the case of E3, the first year at Memuro with Serbian planting. In E3, positive correlations were recorded both between yield and protein content and yield and oil content, whereas a strong negative correlation was found between protein content and oil content. These unusual correlation coefficients at the Japanese site were due to the lack of regularity in yield ranking among the varieties of different maturity groups, as was the case in E1 (Table 4), which supports Vollman et al. (2000) in that a variation in environmental parameters which can promote both yield and protein content of a soybean crop could explain the positive correlation between grain yield and protein content. In any case, grain yield and protein content are generally negatively correlated at Memuro, as shown by the results for the traits across the environments (Table 3), where the year with a lower grain yield (E3, E4) had a higher protein content, and vice versa (E5, E6).

5. Conclusion

Soybean varieties created for production in Central and Southeast Europe were successfully tested on a very distant site, Memuro on the Hokkaido Island in Japan. Agronomic performance of European varieties under Japanese conditions was very good, especially with local planting patterns, a factor that is not usually taken into account in similar studies. This suggests that a single variety may have wider adaptability than previously thought possible. This is important for at least two reasons. First, it was proved that germplasm exchange and common research programs between two institutions at distant parts of the globe make sense even for a photoperiodically very sensitive crop such as soybean. This could facilitate widening of the very narrow genetic variability of soybean which is of great importance for soybean improvement. Second, our findings also open the possibility for commercialisation of soybean varieties from geographically very distant areas such as Europe and Japan.

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